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THE FIRING CHARACTERISTICS OF THE STANDARD ATLAS ELECTRIC MATCH

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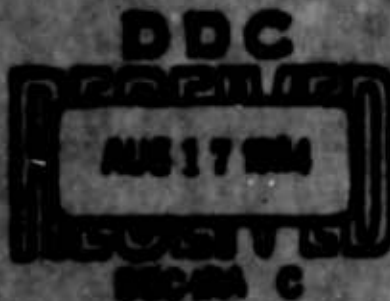
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THE FIRING CHARACTERISTICS OF THE STANDARD
ATLAS ELECTRIC MATCH

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ABSTRACT: The firing sensitivity of both M-100 and M-200 Atlas electric matches is determined for instances when the firing signal duration is in the range 1 to 6 milliseconds. Tests were conducted by supplying either a constant voltage or constant current pulse to the match. The results indicate that there is no significant difference between these matches or between lots of matches. The energy and voltage required to reliably fire these matches within six milliseconds are described as a function of pulse duration.

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The work performed and reported herein was funded by Task No. NOL-649. The characteristics of the electrical ignition sensitivity of both the M-100 and M-200 Atlas Electric Matches have been accurately determined when electrical signals of short duration are applied.

The results of this study should be useful to those concerned with igniting electric matches reliably by the application of short duration electrical signals.

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I. INTRODUCTION

1. The "standard Atlas electric match" is an electrically initiated match manufactured by the Atlas Powder Company, Wilmington 99, Delaware. It comes in two types, the M-100 and M-200 electric match. The only difference between M-100 and M-200 matches is the manner in which the bridge wire is connected. The M-100 employs soldered bridge wire construction and the M-200, welded bridge wire construction. The appearance, construction and method of manufacture of the standard Atlas electric match are described in reference (a).

2. Both the M-100 and M-200 electric matches have been successfully used by NOL in ordnance applications. The Atlas M-200 electric match is presently employed in an application where the match is to be fired by an essentially constant voltage pulse of less than six milliseconds duration. Although some studies have been made of the sensitivity of both types of standard Atlas electric match (references (a) and (b)), accurate constant voltage sensitivity data are incomplete in this time range. Furthermore, the variation in firing sensitivity from one lot of matches to another has not been determined. The purpose of this study is to determine the voltage and energy required to reliably fire the M-200 match when the duration of the firing signal is less than six milliseconds.

II. THEORY

3. A detailed analysis of the theory involved in the firing of electroexplosive devices, such as the standard Atlas electric match, is given in references (c) and (d). In brief, an electric match is fired by supplying sufficient electrical energy to the bridge wire to cause it to become hot enough to ignite the adjacent pyrotechnic mix. The electrical energy received by the match during the pulsing interval is given by the equation

$$E = \int_0^t VI dt, \quad (1)$$

where E is the energy in joules, V is the voltage across the match in volts, I is the current through the match in amperes and t is the duration of the pulse in seconds. The energy required to bring the bridge wire to firing temperature is minimum under adiabatic conditions, that is, when there is no heat loss from the bridge wire to its surroundings. Adiabatic

conditions are approached as the duration of energy pulse is decreased.

III. EXPERIMENTAL

4. With the exception of Lot 262-23, all matches used in this study are from lots which have been tested and certified by the Atlas Powder Company and/or the Eureka Williams Company to meet the specification requirements of reference (e). Reference (e) requires that all matches tested have a resistance of 1.10 to 1.30 ohms and that they fire when a square wave generator passes "a square wave pulse current of 1.0 ± 0.05 amperes through the electric match bridge wire for a maximum of 6.0 milliseconds" when the match is conditioned at $-65 \pm 5^\circ\text{F}$. The certified resistance range of Lot 262-23 is 1.20 to 1.40 ohms. The resistance distribution of 68 matches of this lot is shown graphically in Fig. 1.

5. The first tests conducted were constant current pulse tests on M-100 and M-200 matches in the range 1 to 5 ms. Available constant current power supplies did not have response times sufficiently short for tests of this nature. Therefore, constant current was achieved by using the system shown in Fig. 2. A constant voltage was impressed across a ballast resistor (12.5 ohms, 400 watts), an ammeter, the match or a standard resistor whose resistance (1.178 ohms) was in the range of resistance of the match, and a solid state pulse switch, all in series. A Harrison Laboratory Inc. Model 814A (0 - 36 V, 0-25 A) power supply was used as the constant voltage source. The solid state pulse switch, built by A. R. Reed of this Laboratory, controlled the pulse duration. This pulse switch had a rise time of 5 microseconds, a fall time of 100 microseconds and a precision of better than 50 microseconds as measured on an interval timer. The residual current through the solid state pulse switch was less than 5 milliamps. Because of the small overall change in resistance of the system, the decrease in current during the pulse caused by the increase in resistance of the match is insignificant.

6. The procedure involved in test firing a match is to:
a. substitute the standard resistor for the match in the circuit by means of a knife switch, b. adjust the solid state switch to give desired pulse duration, c. close the solid state switch, d. adjust the constant voltage to give the desired ammeter reading, e. open the solid state switch, f. replace the standard resistor with the match by means of the knife switch, g. fire (or attempt to fire) the match. Using this system and procedure, constant current pulse tests were conducted for 1, 1.5, 2, 3 and 6 ms pulses. The tests

were conducted in the Probit manner as described by reference (f). For each time interval, the per cent fired was plotted as a function of current through the standard resistor on accumulative probability paper and the straight line that best fitted the points visually was drawn. The mean firing current was read from the line at the 50% intercept. The standard deviation was determined by subtracting the mean current from the value at the 84.13% intercept. A summary of the results is given in Table I. A plot of mean firing current versus pulse duration is given in Fig. 3. Applicable results of reference (a) are also plotted for comparison.

Table I. Constant Current Tests

<u>Atlas Match Type</u>	<u>Pulse Duration (ms)</u>	<u>Number of Matches Tested*</u>	<u>Mean Current (Amperes)</u>	<u>Standard Deviation (Amperes)</u>	<u>Lot Number</u>
M-100	1.0	55	1.635	0.040	268-31
M-100	1.5	66	1.357	0.033	268-31
M-100	2.0	90	1.182	0.030	268-31
M-100	3.0	30	0.992	0.014	268-31
M-100	6.0	32	0.722	0.014	268-31
M-200	2.0	37	1.132	0.045	265-24
M-200	2.0	17	1.205	0.037	267-8

*All matches which failed to fire when tested were successfully fired by a 2.0 ms, 2.69 amp pulse.

7. The next series of tests conducted were constant voltage pulse tests on M-200 matches in the range 2 to 6 ms pulses. Because of the problem of switching and switch and lead resistance, available constant voltage power supplies could not be used to supply a constant voltage pulse directly across the match. Instead, the system suggested by reference (g) and diagrammed in Fig. 4 was used. Here, the control unit produced a square wave pulse at the base of the transistor. The transistor acts as a switch and governs both the pulse length and voltage across the match. The voltage across the match is proportional to the voltage from the control unit. A Harrison Laboratory Inc. Model 814 Power Supply supplied the firing energy to the match. In order to accurately measure the voltage across the match, a reference voltage was obtained from mercury cells and a dropping resistor. This reference voltage was accurately measured with the potentiometer and adjusted to be equal to the desired voltage across the match. Then, with the standard resistor (1.178 ohm) in the place of the match, the control unit's output was adjusted so that the voltage across the match was equal to the reference voltage. The difference

between the reference voltage and the voltage across the standard resistor was measured with a differential oscilloscope. The standard resistor was then removed and replaced with the match to be tested. The tests were conducted and calculations made in the Bruceton manner as described in reference (h). The voltage reported is the voltage across the standard resistor. A summary of the data is shown in Table II. The mean firing voltage plus five standard deviations are plotted as a function of pulse duration in Fig. 5.

Table II. Constant Voltage Tests,
Atlas M-200 Matches, Lot 265-24

<u>Pulse Duration (ms)</u>	<u>Number of Matches Tested</u>	<u>Number Fired</u>	<u>Number Failed*</u>	<u>Mean Voltage (Volts)</u>	<u>Standard Deviation (Volts)</u>
2.0	21	14	7	1.485	0.023
3.0	25	12	13	1.204	0.015
4.0	25	15	10	1.063	0.011
6.0	25	13	12	0.911	0.009

*All matches which failed to fire when tested were successfully fired by a 1.80 volt, 3 ms pulse.

8. Tests conducted in the Probit manner give a more accurate determination of standard deviation than do tests conducted in the Bruceton manner. For this reason the next series of tests were constant voltage, 3 ms pulse duration tests conducted in the Probit manner. The variable of the tests was the ratio, V_M/R_M , where V_M is the voltage across the match at the midpoint of pulse duration and R_M is the measured resistance of the match before it is pulsed. The resistance of each match was measured before it was pulsed through the use of a bridge whose output current was limited to 30 ma. This series used the match firing apparatus diagrammed in Fig. 4. The value of V_M was determined through the following calculations.

9. When two reference resistors of different value are placed, one at a time, in the match position of the firing apparatus, different voltage values across each resistor are observed during the pulses, even though the constant voltage from the source is the same. This is due to lead resistance in the circuit between the constant voltage source and the reference resistors. This lead resistance can be calculated from the equation

$$R_L = - \Delta V / \Delta I, \quad (2)$$

where R_L is the lead resistance, ΔV is the difference in voltage during the pulse across each of the two reference resistors, and ΔI is the difference in current, calculated from V/R , during the pulse through each of the two reference resistors. The lead resistance for the apparatus was found to be 0.166 ohm. Assuming that the total voltage is constant and fixed and assuming that one reference resistor is the standard resistor with a resistance of R_S and the other is the match, the following equation applies:

$$(V_S/R_S)R_L + V_S = (V_M/R_M)R_L + V_M \quad (3)$$

where V_S is the voltage across the standard resistor. Substituting the lead resistance value of 0.166 ohm and the standard resistor resistance value of 1.178 ohms, Eq. (3) was rearranged as follows:

$$V_M = V_S R_M / (0.8765 R_M + 0.1455) \quad (4)$$

10. The per cent fired was plotted as a function of the ratio V_M/R_M , essentially the current through the match, on accumulative probability paper. The straight line that visually best fitted the points was drawn. The mean firing V_M/R_M value was read from the line at the 50% intercept and the standard deviation was determined by subtracting the mean value from the value at the 84.13% fired intercept. The firing data are reported in Tables III and IV.

Table III. V_M/R_M 3.0 ms Pulse Test, Atlas M-200 Matches
Lot 265-24

$V_M/R_M \pm 0.005$	Fired/Attempts	Per cent fired
0.965	0/2	0
0.975	0/0	-
0.985	0/5	0
0.995	1/5	20.0
1.005	0/6	0
1.015	1/7	14.3
1.025	2/7	28.6
1.035	3/6	50.0
1.045	7/11	63.6
1.055	4/5	80.0
1.065	4/6	66.7
1.075	3/4	75.0
1.085	5/5	100.0
1.095	3/3	100.0
1.105	2/2	100.0

Mean $V_M/R_M = 1.037$ volts/ohm. Standard deviation = 0.021 volts/ohm.

Table IV. V_M/R_M 3.0 ms Pulse Test, Atlas M-200 Matches
Lot 262-23

$V_M/R_M \pm 0.005$	Fired/Attempts	Per cent fired
1.057	10/10	100.0
1.037	6/9	66.7
1.027	7/10	70.0
1.017	12/33	36.4
1.007	0/3	0

Mean $V_M/R_M = 1.024$ volts/ohm.

Standard deviation = 0.019 volt/ohm

11. The constant voltage tests did not result in absolutely constant voltages across the match. Instead, a very small voltage increase was observed on the oscilloscope. This voltage increase was due to the increase in match resistance during the pulsing interval. A typical test gave the following results. A 1.300 V initial voltage was placed across a match whose initial resistance was 1.230 ohms. A 5 mv voltage increase was observed during the pulsing interval, making the final voltage across the match 1.305 V. The lead resistance was assumed to be a constant 0.166 ohms. The initial conditions were substituted in place of the standard resistor values and the final conditions were substituted in place of the match values of Eq. (3). Equation (3) was then solved for the final resistance of the match (1.274 ohms). Thus, a typical resistance increase of 3.5% is obtained during the firing pulse.

IV. RESULTS

12. If one assumes the resistance of all matches to be 1.30 ohms and constant during the pulsing interval, and multiplies this value by the mean firing current, the calculated voltage is the mean firing voltage for matches whose resistance is 1.30 ohms. If the value, 1.30 ohms, is multiplied by the mean plus five standard deviations firing current, the calculated voltage when applied to a match will cause 99.99997% (assuming normal sensitivity distribution) of the matches whose resistance is 1.30 ohms to fire. Matches with resistance lower than 1.30 ohms (including all matches which meet the requirements of reference (e)) would have a higher percentage of fires when the same voltage is applied to them. These voltages are plotted as all fire voltage vs pulse duration in Fig. 6. Also plotted on this graph are the mean plus five standard deviations firing voltages as obtained from the constant voltage Bruceton tests. The all-fire voltage (better than 99.99997% firing of all matches meeting requirements of reference (e)) can be read from the resulting curve as a function of pulse duration for times less than six milliseconds.

13. The maximum energy necessary for match firing was determined from the equation

$$E = (V^2/R)\Delta t, \quad (5)$$

where V is the all-fire voltage read from Fig. 6, R is 1.30 ohms and Δt is the pulse duration in seconds. A plot of maximum firing energy necessary versus pulse duration is shown in Fig. 7. The mean firing energies were calculated from the equation

$$E = I^2 R \Delta t, \quad (6)$$

where I is the mean firing current of the constant current tests, R is the mean match resistance (1.20 ohms) and Δt is the pulse duration in seconds. The mean firing energies are also plotted in Fig. 7. Straight lines, which best represented the plotted points, were drawn for both the mean and maximum necessary firing energies. These lines indicate a slight decrease in necessary energy as the pulse duration is decreased. The maximum energy required for firing at 6 ms (48,000 ergs) is well within the requirements of reference (d).

14. The results of this study indicate that there is no significant difference in sensitivity between Atlas M-100 and M-200 electric matches or between lots of matches tested. The energy and voltage required to reliably fire these matches within six milliseconds are described as a function of pulse duration in Figs. 6 and 7.

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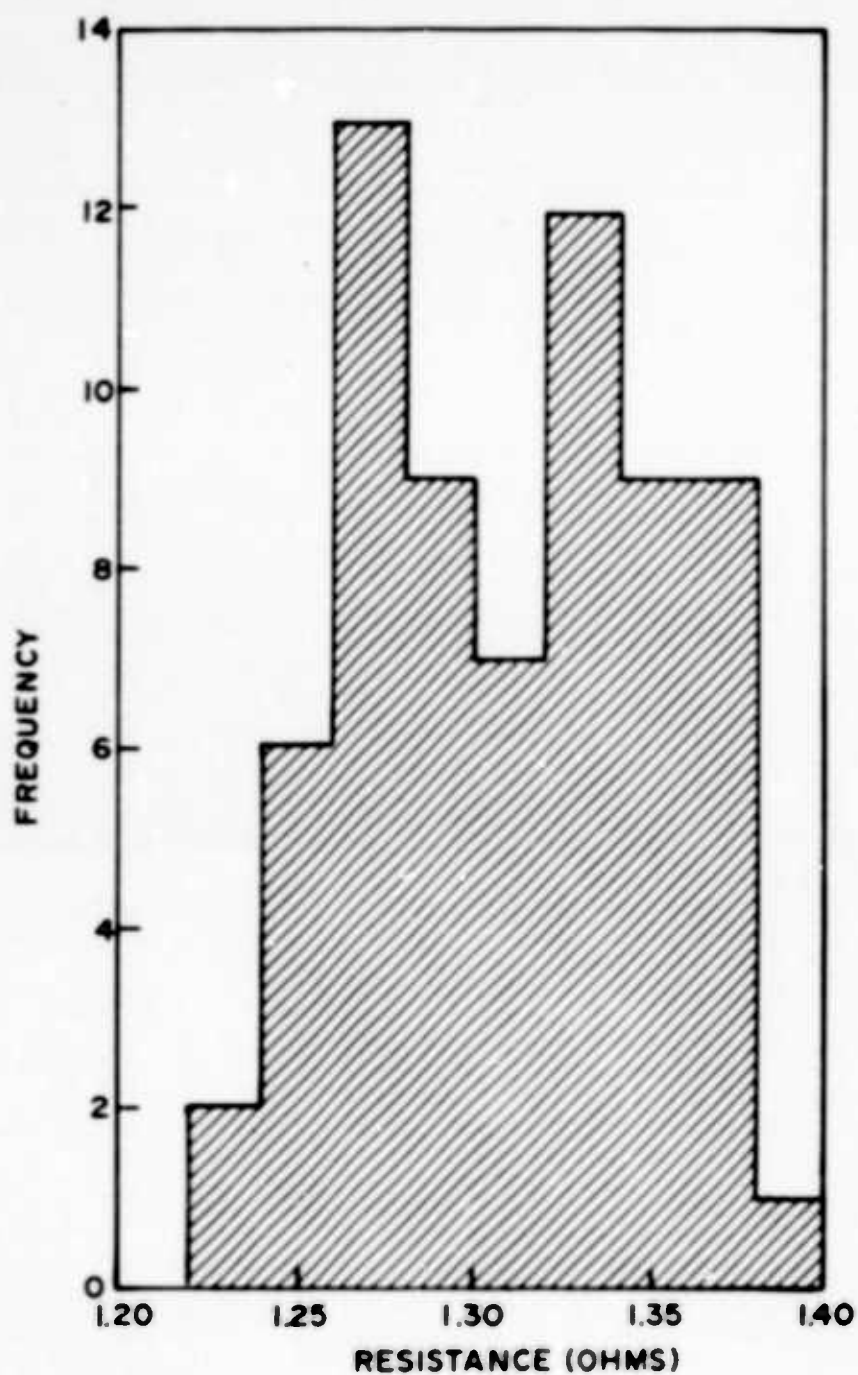


FIG. 1 RESISTANCE DISTRIBUTION M-200 LOT 262-23

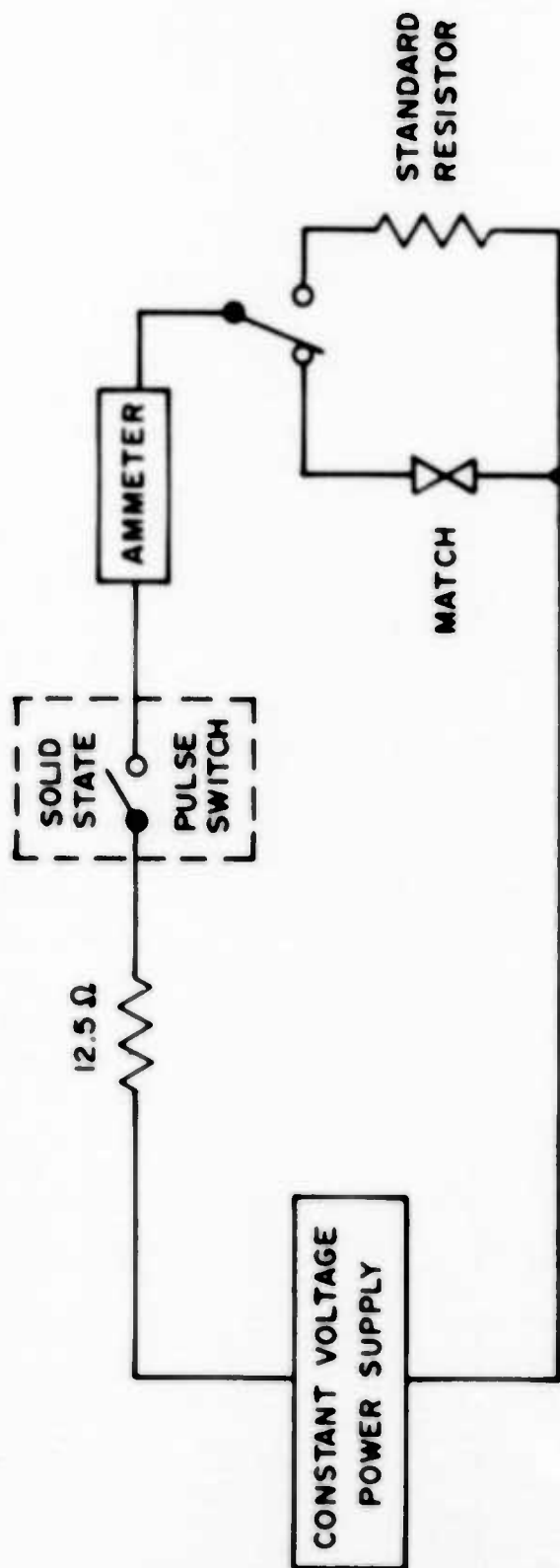


FIG. 2 DIAGRAM OF APPARATUS USED IN CONSTANT CURRENT PULSE TESTS

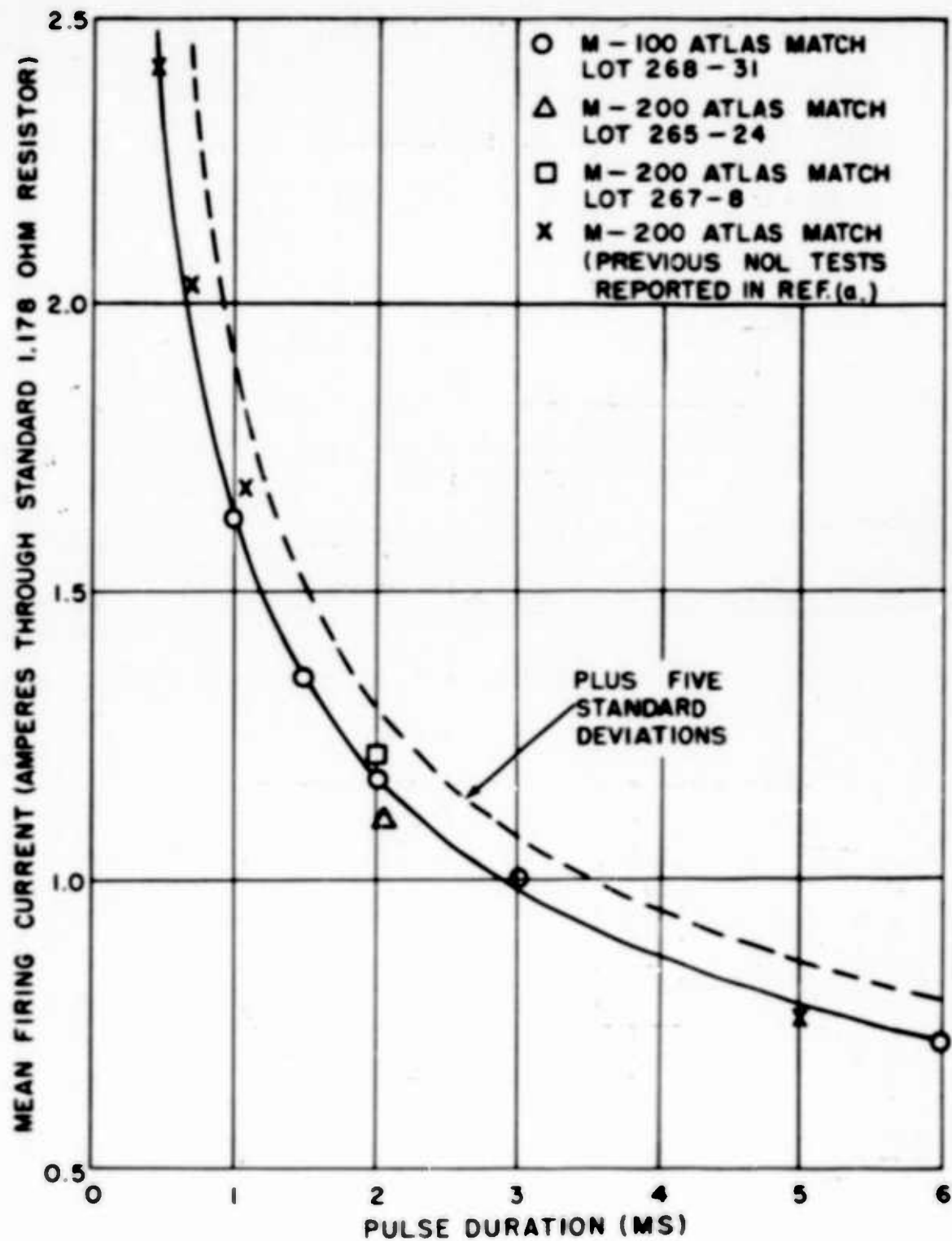


FIG. 3 CONSTANT CURRENT TEST

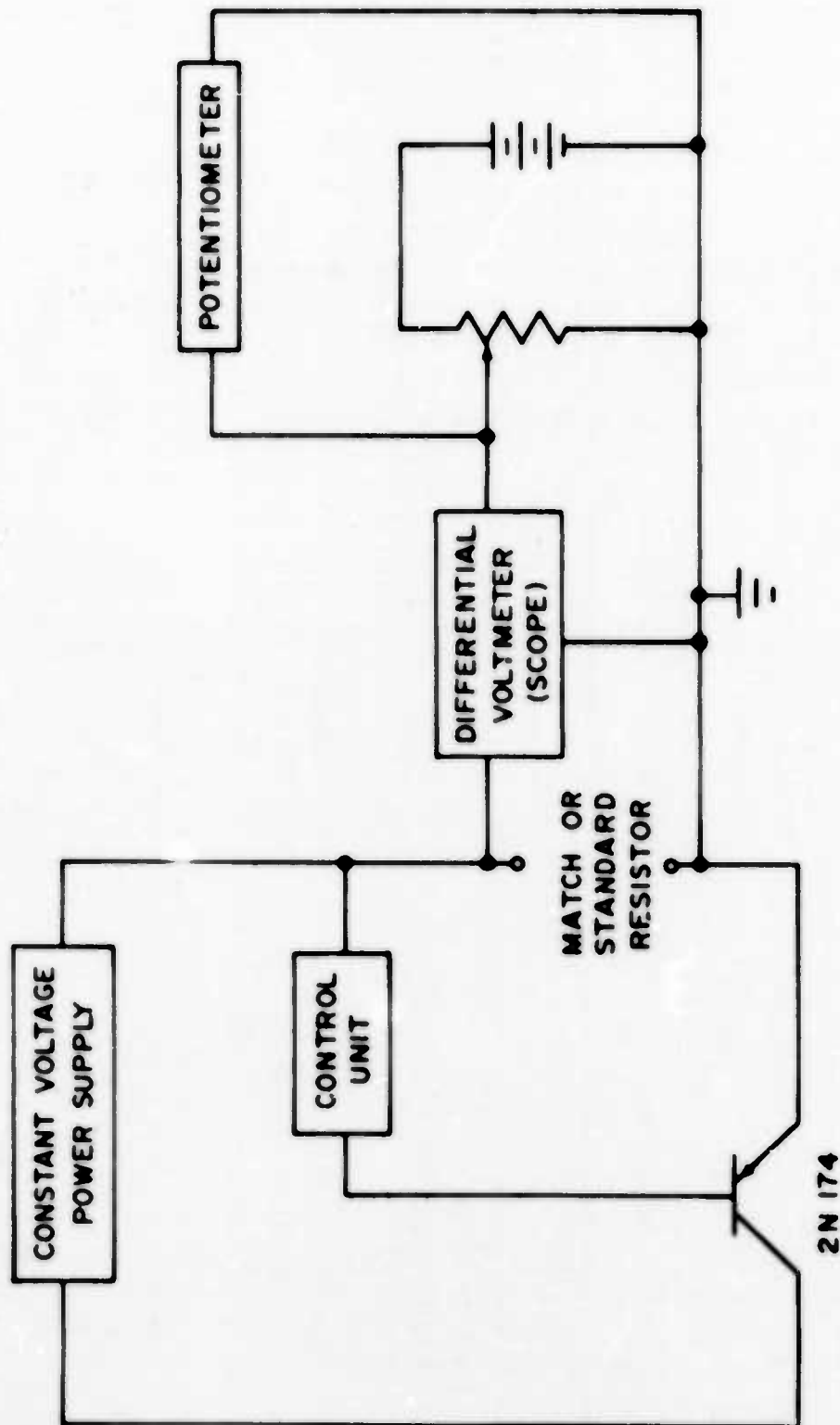


FIG. 4 DIAGRAM OF APPARATUS USED IN CONSTANT VOLTAGE PULSE TESTS

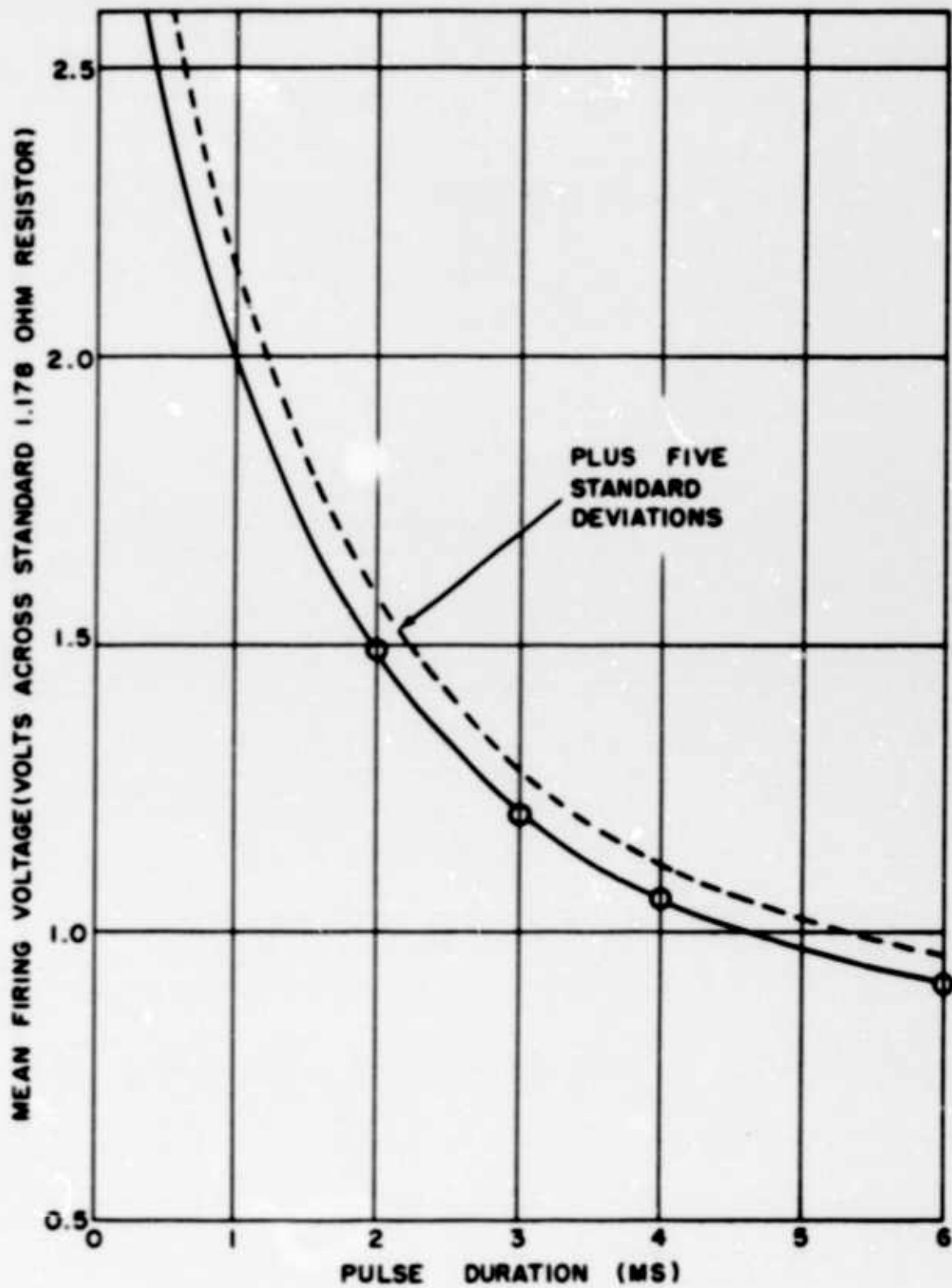


FIG. 5 CONSTANT VOLTAGE TESTS M-200 ATLAS ELECTRIC MATCH LOT 265-24

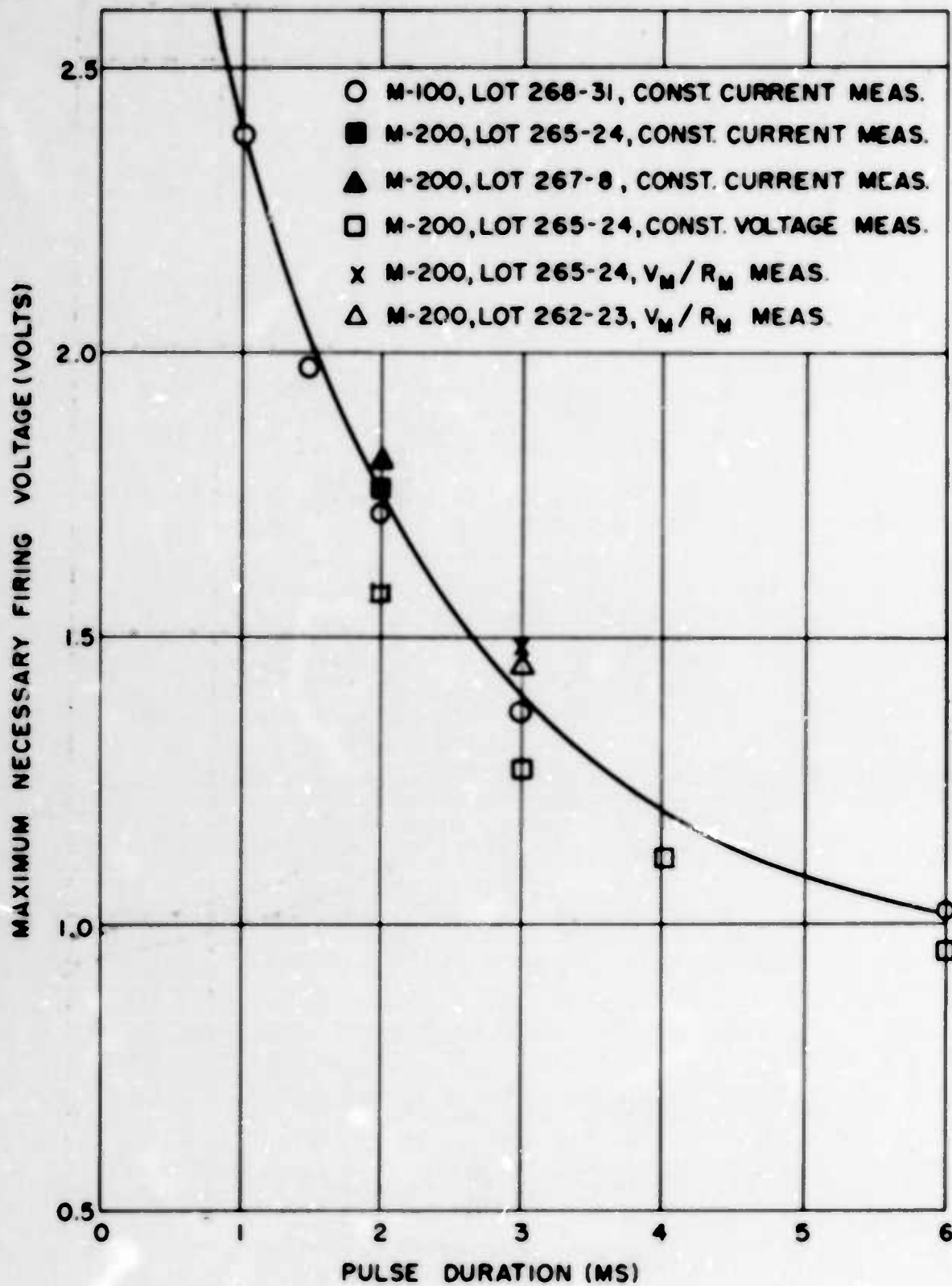


FIG. 6 ALL-FIRE VOLTAGE OF STANDARD ATLAS ELECTRIC MATCH

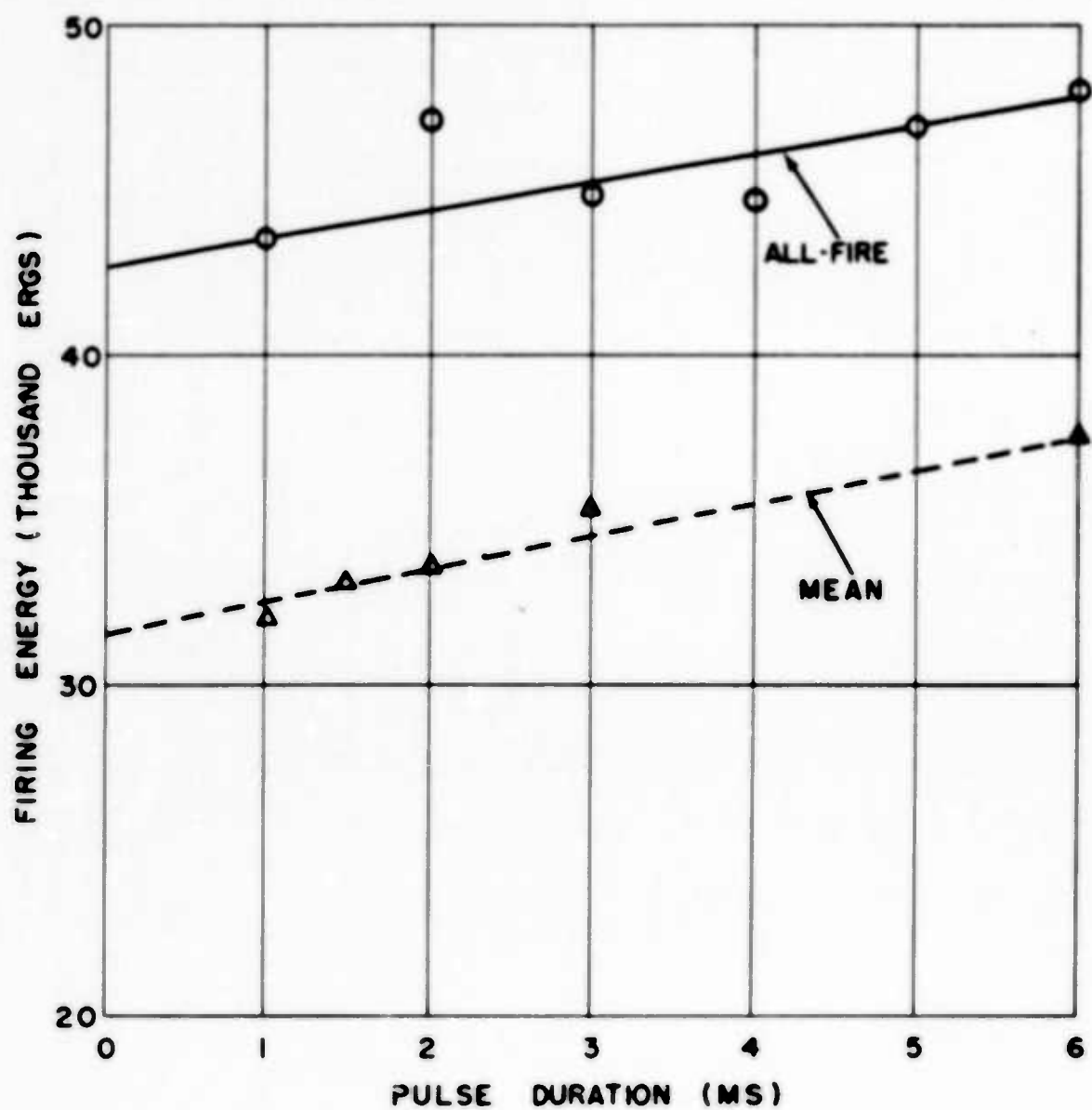


FIG. 7 ALL-FIRE ENERGY OF STANDARD ATLAS ELECTRIC MATCH